Article

Exploring the Effects of Working Memory on Time Perception in Attention Deficit Hyperactivity Disorder

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Abstract

Children with attention deficit hyperactivity disorder (ADHD) are often reported to have deficits of time perception. However, there is a strong relation between performance on tasks of working memory and time perception. Thus, it is possible that the poor performance of children with ADHD on time perception results from their deficit of working memory. In this study, the working memory of participants was separately assessed; therefore, we could explore the relationship between working memory and time perception of children with ADHD. Fifty-six children with ADHD and those of healthy controls completed tasks measuring working memory and time perception. The results showed that the time discrimination ability of children with ADHD was poorer than that of controls. However, there was a strong association between time perception and working memory. After controlling working memory and intelligence, the time discrimination ability of children with ADHD was not significantly poorer than that of controls. We suggest that there is an interdependent relationship between time perception and working memory for children with ADHD.

Keywords

Attention deficit hyperactivity disorder, N-back task, timing, time perception, working memory

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Introduction

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder (American Psychiatric Association, 2013). The behavioral symptoms of ADHD (inattention, hyperactivity, and impulsivity) are well documented; however, there is much debate about the cognitive deficits leading to these behavioral symptoms. Many hypotheses have been proposed to account for the behaviors involved in ADHD, including impaired behavioral inhibition and executive function (Barkley, 1997, 2012), impairment in the regulation of arousal (Sergeant, 2000), delay aversion (Sonuga-Barke, 2002; Sonuga-Barke, Bitsakou, & Thompson, 2010), working memory deficits (Kane et al., 2007; Pickering, 2006), and temporal processing deficits (Huang et al., 2012; Smith, Taylor, Rogers, Newman, & Rubia, 2002; Sonuga-Barke et al., 2010; Toplak, Dockstader, & Tannock, 2006). However, some constructs mentioned above may be dependent on each other. For instance, Barkley's (1997) ADHD behavioral inhibition model offers an explanation of how temporal processing might be impaired in ADHD. The poor inhibitory control affects working memory, which subsequently affects temporal processing. In this study, we test the temporal processing hypothesis because inconsistencies in performance on time perception tasks among children with ADHD have been demonstrated. We begin with an explanation of the relationship between timing and working memory that motivates this work.

Timing refers to the ability to deal with the temporal domain in behavior (Noreika, Falter, & Rubia, 2013). Timing functions are commonly divided into three domains: motor timing, perceptual timing, and temporal foresight (Rubia, 2006), which allows people to predict and anticipate events, to provide the most adaptive behavior (Toplak, Rucklidge, Hetherington, John, & Tannock, 2003). Timing can be connected to the core symptoms of ADHD (e.g. impulsivity) (Baumann & Odum, 2012; Wittmann et al., 2011); impulsivity can even be defined as a pattern of temporally inadequate behavior in which future consequences are not contemplated (Smith et al., 2002).

There are many ways to evaluate timing abilities. The most common are duration/time motor reproduction, motor tapping, and duration discrimination. However, duration/time motor reproduction tasks and motor timing tasks not only evaluate time perception but also involve eye–hand coordination (Yang et al., 2007). Comparatively, duration discrimination tasks involve directly asking participants to determine which of two successive time intervals is longer. They do not require a rapid motor response and are simpler assessments of time perception. As they reduce the need for eye–hand coordination and cognitive ability (Smith et al., 2002; Yang et al., 2007), they are most often used in studies of timing in children with ADHD. It was found that children with ADHD present with higher discrimination threshold when performing these tasks. There must be a large enough discrepancy in the two intervals for children with ADHD to be aware of the difference. Otherwise, there will be a higher error rate due to misjudging of the discrepancy between the two intervals (e.g. Smith et al., 2002; Toplak et al., 2003; Yang et al., 2007). However, some studies do not show consistent results (e.g. Radonovich & Mostofsky, 2004; Rubia, Taylor, Taylor, & Sergeant, 1999).

When conducting the duration discrimination tasks, participants are asked to compare two or three successive intervals (of milliseconds or seconds). The gap between them is very short. Participants must temporarily remember the stimulus that is presented (item 1), then wait for the second or the final stimulus (item 2) to make a comparison. This type of operational method is the same as the function of working memory (Baddeley, 1998; Goldman-Rakic, 1995). In this example, estimation of time perception involves working memory. Some studies have demonstrated that time discrimination tasks involve working memory (Pouthas & Perbal, 2004; Radonovich & Mostofsky, 2004; Sonuga-Barke et al., 2010; Toplak et al., 2003). For example, Radonovich and Mostofsky (2004) tested ADHD children using 550-millisecond short and 4-second long intervals. In terms of short-interval discrimination, children with ADHD children did not show poorer performance than healthy controls. However, they did show poorer performance on longer 4-second duration discrimination task. They believed that these results are consistent with those of patients with frontal lobe damage. Thus, they proposed that children with ADHD do not demonstrate impairment of timing mechanisms, but rather in their ability to apply information related to time. The poor timing performance of children with ADHD may be associated with impairment of working memory or strategic application ability (Radonovich & Mostofsky, 2004).

In addition, many studies have confirmed deficits in working memory in children with ADHD (e.g. Dowson et al., 2004; Gathercole et al., 2008; Karatekin, 2004; Kempton et al., 1999; Kuntsi, Oosterlaan, & Stevenson, 2001; Mariani & Barkley, 1997; Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004). In particular, in Barkley's (1997) ADHD behavioral inhibition model, it was noted that deficits in behavioral inhibition impact on working memory and then abnormalities in working memory in ADHD lead to impairments in some secondary functions including sense of time, especially the inability to accurately determine and reproduce intervals. This is because time perception must be retained in the working memory (Barkley, Koplowitz, Anderson, & McMurray, 1997). Therefore, it is plausible that timing of children with ADHD is influenced by their working memory, and inconsistencies across studies may have resulted from variation in working memory.

However, Noreika et al. (2013) suggested that timing is related to other executive functions (especially working memory), and when these functions were controlled for statistically, children with ADHD still demonstrated timing deficits. But they suggested that more research is needed to support this conclusion (for a review, see Noreika et al., 2013). Thus, it is not completely clear whether children with ADHD experience timing deficits resulting from their working memory deficits. The main reason is that the association between timing function and working memory has not been elucidated. One school of thought is that they have a subordinate relationship and can be looked at together (Barkley, 1997; Sonuga-Barke et al., 2010). Another school of thought is that they are independent of one another, and timing deficit in ADHD is an independent impairment domain. That is, when controlling for other cognitive functions (e.g. working memory), children with ADHD have timing deficits (Noreika et al., 2013).

In this study, the focus was on time perception evaluated by time discrimination tasks because time discrimination tasks minimize the motor demands of timing performance. However, the time discrimination tasks involve working memory. Few studies have manipulated the task difficulty of time discrimination tasks to demonstrate the influence of working memory on time perception. In this study, the level of difficulty of time discrimination tasks was manipulated, the relations between working memory and task difficulty were assessed, and predicted more difficult time discrimination tasks require the use of working memory. Through this manipulation and by statistically controlling for working memory, the aim of this study was to elucidate if there are abnormalities in time perception ability in children with ADHD.

Methods

Participants

Twenty-eight children with ADHD (28 males) and 28 children without ADHD (22 males, 6 females, control group), aged 7–13 years (enrolled in Grade 1 to 6), participated in this study. Comparisons of participants in terms of age, intelligence estimates, and working memory capacity are shown in Table 1. Students who met the eligibility requirements for enrollment in this study, and who were attending an elementary school in Taichung City, Taiwan, were identified by special education teachers. Children with ADHD were diagnosed by experienced child psychiatrists who administered structured interviews and Chinese-language version of standardized questionnaires, based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition diagnostic criteria for ADHD (American Psychiatric Association, 2013). Exclusion criteria included diagnosis of mood disorder, anxiety disorder, dissociative disorder, or psychotic disorder. Eighteen out of 28 participants with ADHD had never taken any medicine, while the rest did, but not on the assessment day. Healthy controls were enrolled from schools in the same communities as the participants with ADHD.

Table 1. Comparisons of age, intelligence, and working memory capacity among the two groups of participants.

	ADHD group ($n=28$)		Control group ($n=28$)		
	M	*SD*	*M*	*SD*	*F*
Age	9.66	1.56	9.78	1.61	0.09
Estimated FSIQ	102.32	9.45	110.85	10.79	9.89**
Block Design	10.89	2.28	11.32	2.64	0.42
Similarities	11.96	2.80	12.86	2.48	1.60
Digit Span	9.11	1.59	10.68	2.06	10.21*
Symbol Search	9.25	2.62	11.64	3.48	8.46*
N-back task accuracy rate	0.36	0.16	0.47	0.18	5.41*

ADHD: attention deficit hyperactivity disorder; FSIQ: full-scale intelligence quotient.
*$p < 0.05$; **$p < 0.01$.

Measures

1. Short-form of the Wechsler Intelligence Scale for Children 4th edition (WISC-IV): The full-scale intelligence quotient (FSIQ) of participants was estimated using the fourth edition of the WISC-IV (Wechsler, 2003/2007) with subtests for Similarities, Block Design, Digit Span, and Symbol Search. For the selected tetrad, the mean differences between estimated and actual FSIQ were within 0.01 IQ points, and the correlations were between .92 and .93 (Chen, Hua, Chang, & Chen, 2011).
2. N-back task: In recent years, laboratory studies have made use of the N-back task to evaluate working memory (e.g. Jaeggi, Buschkuehl, Perrig, & Meier, 2010; Klein, Wendling, Huettner, Ruder, & Peper, 2006). This task is written in Visual Basic computer programming language. The contents are based on the Braver et al. (1997) version. During this task, a succession of letters appears in the center of the screen, such as B, C, D, F, G, H, J, K, M, N, P, Q, R, S, T, V, X, Z. Working memory capacity is estimated by the manipulation of n. As the level of difficulty of the N-back task can be adjusted, the larger the n, the larger the working memory capacity. When $n=1$, the participant needs to compare the present letter with the previous letter. If the letters are different, he/she presses the left Shift key. If the letters are identical, he/she presses the right Shift key. When $n=2$, the participant needs to compare the stimulus two turns back. Before the formal 1-back test, the participant is allowed 10 practice trials. For the 2-back test, the participant is allowed 20 practice trials. Once formal testing begins, there are four sections. In each section, there are 24 trials, as well as eight targets (total 32 targets, 64

nontargets). Each stimulus appears for 500 milliseconds, and there is a 1000-millisecond interval between trials. In this study, the task accuracy rate served as a variable on statistical analysis. The adjusted formula for accuracy rate was: (hits ÷ target number) – (false alarms ÷ nontarget number). Braver et al. (1997) made use of brain imaging techniques and found that during the performance of N-back tasks the prefrontal cortex is activated, which is responsible for working memory. Jaeggi et al. (2010) showed that the N-back task is highly related to the memory span subtest, meaning that the N-back task measure and working memory evaluated on the memory span subtest are the same construct. Thus, the N-back task is suited to estimating working memory in research studies. In this study, the average of the accuracy rates for 1-back and 2-back was considered the working memory index.

3. Time discrimination task: The time discrimination task is a computerized visual test of time perception ability. The contents are based on the versions of Vrabel (2009) and Levin, Goldstein, and Zeiniker (1984). For each trial, three Chinese characters which refer to the meanings for top ("上"), center ("中"), and bottom ("下"), respectively, appear on the screen in the corresponding locations, i.e. top, center, and bottom. The characters do not necessarily appear or disappear at the same time. For example, in one trial that lasted for 12 seconds, the "下" character appeared first at the bottom of the screen and disappeared in the 10th second (total time 10 seconds). The "中" character appeared in the center of the screen in the 5th second and disappeared in the 11th second (total time 6 seconds). The "上" character appeared at the top of the screen in the 10th second and disappeared in the 12th second (total time 2 seconds). Following the completion of each trial, the participant was asked to press a key to choose which character appeared for the longest amount of time. There was no time limitation. The entire task comprises 24 trials. Among them, 12 included three intervals of 2, 6, and 10 seconds, and 12 included three intervals of 4, 6, and 8 seconds. One point was given per correct answer. The total score was the total number of items answered correctly. In addition, to determine the working memory capacity used during time discrimination task, the task was divided into two levels of difficulty. Each level comprises 12 trials. For the easy level, in six trials, two characters appeared at the same time but disappeared at different times. In the other six trials, two characters appeared at different times but disappeared at the same time, as shown in Figure 1. For the difficult level, the three characters appeared and disappeared at different times.

Procedure

The approval of the research ethics committee was obtained prior to the onset of data collection. All children were enrolled from elementary schools in Taichung

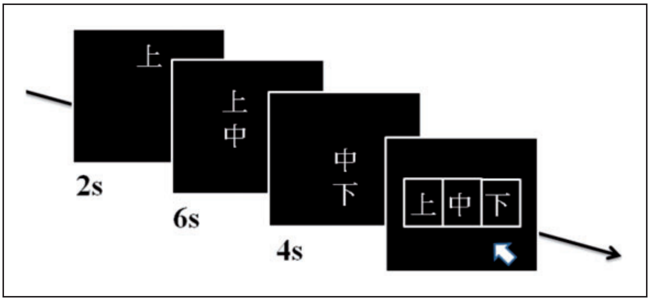

Figure 1. Time discrimination task of easy level. In one of the examples, the "中" (center) and "下" (bottom) characters disappeared at the same time. Participants were to determine which character appeared on the screen for the longest amount of time.

City, Taiwan. Data collection was carried out after receiving parental consent. Once parents allowed their children to participate, the children were asked to sign an assent form to participate in the tests or tasks. Each participant was first administered the short-form WISC (Chen et al., 2011) to obtain intelligence estimates (approximately 30 minutes). Finally, all of the participants completed all of the tasks including N-back task and time discrimination task (approximately 30 minutes). Tasks were implemented in random order during the morning individual study period and lunch break and were gradually completed in sessions over a period of days.

Data analyses

In this study, analysis of covariance (ANCOVA) was used to control for working memory and compare time perception performance between ADHD group and control group.

Results

Comparisons between the two groups in terms of age, intelligence, and working memory capacity are shown in Table 1. There were no differences in age between the two groups. However, there were differences in estimated FSIQ (IQ); the ADHD group obtained a lower IQ score than the control group. There were also differences in working memory capacity; ADHD group had a lower score than healthy controls.

The performances of the two groups on time discrimination tasks are presented in Table 2. As expected, the accuracy rate decreased as the level of difficulty increased. From the results of two-way analysis of variance (ANOVA), there was no group effect ($F(1, 54) = 1.92$; $p = 0.17$; $\eta^2 = 0.03$). However, there was level of difficulty effect ($F(1, 54) = 9.60$; $p < 0.01$; $\eta^2 = 0.15$). In addition,

Table 2. Performances of the two groups on time discrimination tasks of differing levels of difficulty.

	ADHD group ($n = 28$)		Control group ($n = 28$)		
	M	*SD*	*M*	*SD*	$t(54)$
Easy level	0.63	0.17	0.64	0.23	0.32
Difficult level	0.51	0.20	0.63	0.22	2.21*

ADHD: attention deficit hyperactivity disorder.
*$p < 0.05$.

there was significant interaction between groups and levels of difficulty ($F(1, 54) = 5.62$; $p < 0.05$; $\eta^2 = 0.09$). On further analysis, at difficult level, the ADHD group showed poorer performance than the control group ($t(54) = 2.21$; $p < 0.05$). However, there was no significant difference between the groups at easy level ($t(54) = 0.32$; $p = 0.75$).

As Table 1 shows, children with ADHD obtained lower scores on intelligence and working memory tests than that of controls. Therefore, when carrying out comparisons of children with ADHD and typically developing children, it is necessary to control for the influences of intelligence and working memory.

This study went a step further to include intelligence and working memory as the control variable in the covariate of ANCOVA for analyzing the performance on time discrimination tasks of difficult level between children with ADHD and healthy children. When the FSIQ estimates (the covariate) were controlled, no significant differences were found between the two groups ($F(1, 52) = 2.98$; $p = 0.09$; $\eta^2 = 0.05$). In addition, when the scores of N-back task were controlled, the differences on time discrimination tasks between the two groups were not significant ($F(1, 52) = 1.53$; $p = 0.22$; $\eta^2 = 0.03$).

As Table 1 shows, children with ADHD obtained lower scores on WISC-V Digit Span and Symbol Search subtests than that of controls. The Digit Span tests were initially designed to measure working memory and attention as a function of working memory (Collum, Rex, & Haier, 2007). When the scores of Digit Span test were included as the covariate of ANCOVA, then again, no significant differences were found between the two groups ($F(1, 52) = 1.59$; $p = 0.21$; $\eta^2 = 0.03$). These results live up to our expectations that working memory plays an important role in time perception, and children with ADHD do not perform worse than controls on the time discrimination tasks after controlling for working memory.

Moreover, we attempted to determine if there are relationships among performances on time discrimination tasks of differing levels of difficulty and N-back task accuracy rates. The results of partial correlation analysis are shown in Table 3 after controlling for intelligence. The associations among performances on time discrimination tasks of easy and difficult levels and N-back task accuracy rate were significant. It is clear that there is a direct

Table 3. Partial correlation coefficients among accuracy rates on time discrimination tasks of differing levels of difficulty and N-back task accuracy rates ($n = 56$).

Variable	1	2	3
1. Time discrimination task of easy level	1		
2. Time discrimination task of difficult level	0.66**	1	
3. N-back task	0.27*	0.46**	1

*$p < 0.05$; **$p < 0.01$.

relationship between time discrimination tasks and working memory. Furthermore, the relationship between working memory and time discrimination tasks of difficult level was a moderate correlation. The relationship between working memory and time discrimination tasks of easy level was a low correlation. As expected, a larger need for working memory on time discrimination tasks of difficult level in comparison to those of easy level.

On the other hand, to examine the influence of working memory on time perception, participants were divided into high- and low-capacity groups based on their performance on N-back task. Mean N-back accuracy of all participants was 0.42. Participants with accuracy rate of 0.42 or higher were placed in the high working memory capacity group ($n = 26$), and those with accuracy rate below 0.42 were placed in the low working memory capacity group ($n = 30$). Analysis was carried out to determine if there is a difference between high- and low-capacity groups on the discrimination tasks. From the results of two-way ANOVA, the level of difficulty of time discrimination tasks showed no significance ($F(1, 108) = 3.28$; $p = 0.07$; $\eta^2 = 0.03$), while working memory capacity showed significance ($F(1, 108) = 23.73$; $p < 0.001$; $\eta^2 = 0.18$). There was no interaction between working memory and time discrimination tasks ($F(1, 108) = 1.85$; $p = 0.18$; $\eta^2 = 0.02$). These findings indicated that differences in working memory capacity result in differences in performance on time discrimination tasks. Regardless of whether the participants are children with ADHD, those with high working memory capacity showed better performance on time discrimination tasks.

Discussion

The major finding of this study was the strong association between time perception and working memory in ADHD. The time discrimination tasks involved working memory. When controlling for working memory, the performance of children with ADHD on time discrimination tasks was not worse than that of controls. This is consistent with the findings of Rubia et al. (1999), but inconsistent with the findings of Noreika et al. (2013). Some previous studies did not find that the ADHD group performed significantly worse on time discrimination tasks than the control group (e.g. Sonuga-Barke et al., 2010; Toplak et al., 2003; Toplak & Tannock, 2005).

However, some studies found that ADHD group appeared to have a time perception deficient (e.g. Smith et al., 2002). One possible cause is that the use of different time perception tasks in different studies, which require different working memory loads and then lead to different discoveries.

Further, our results support an interdependent relationship between time sense and working memory for children with ADHD (Barkley, 1997; Sonuga-Barke et al., 2010) but deviate from the view that the two are independent and that timing deficits are the core issue in ADHD (Noreika et al., 2013). As suggested by Barkley et al. (1997), time perception should be retained in the working memory.

Some researchers believe that impairment of the working memory is the core impairment among children with ADHD and that this impairment leads to the core symptom of inattention (e.g. Pickering, 2006). Kane et al. (2007) demonstrated that those with low working memory capacity tend to lose focus or daydream during cognitive load activities, such as classroom learning. These are the behavioral indicators of working memory capacity overload and the inability to remember relevant information. Therefore, the inability to pay attention in ADHD may be due to the inability to remember all of the relevant information during classroom learning activities. ADHD children transfer their focus to other things, manifesting inattentive behavior. Therefore, it is possible that working memory deficits have been mistaken as attention deficits. Similarly, as time perception should be retained in the working memory, working memory abnormalities cause time perception impairments in children with ADHD (Barkley et al., 1997). Thus, it is possible that working memory deficits have been mistaken as timing deficits. We suggest that working memory capacity should be controlled in exploring the timing deficit of children with ADHD.

Limitations

There were six females in the control group and no females in the ADHD group. Although past studies have not reported differences in working memory between male and female children, it is possible that any existing gender variations influence the findings. Furthermore, the difference in intelligence between two groups could create several uncontrolled confounding variables that could influence the relation between time discrimination and working memory. Future research needs to control these potential confounding variables.

On the other hand, manipulation of short-term intervals to the millisecond was not carried out in this study. Some researchers have suggested that there is a need for different timing mechanisms for different intervals. Processing of short intervals of 2 seconds or less is related to intrinsic timing mechanisms or processing by the cerebellum. Processing of longer intervals of more than 2 seconds is more closely related to working memory (Ivry, 1996; Mangels, Ivry, & Shimizu, 1998; Rammsayer, 1999; Toplak et al., 2003). At the level of milliseconds, time discrimination tasks are purely related to time perception. As the entire task is very brief, there is little possibility for interpretation by the working memory or short-term memory (Smith et al., 2002). However, some studies have demonstrated that time discrimination tasks at the level of milliseconds still involve working memory (Sonuga-Barke et al., 2000; Toplak et al., 2003).

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